Exploring Tasty Fluidics for Designing Food as Computational Artifact

Jialin Deng[a], Patrick Olivier[b], & Florian 'Floyd' Mueller[a]

[a] Exertion Games Lab, Department of Human-Centered Computing, Monash University, Australia,
{jialin, floyd}@exertiongameslab.org
[b] Action Lab, Department of Human-Centered Computing, Monash University, Australia,
patrick.olivier@monash.edu

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ABSTRACT

Contemporary human-food interaction design is predominantly a technology-driven endeavor in which food has not been synergistically employed as a major design material. This article extends a recent approach to food-computation integration that uses food as the primary material to realize computation. We present a "Research through Design" exploration of an edible computational material resulting in a novel design scheme, "tasty fluidics", which enables food items to regulate their flavor and visual presentation computationally. Through reflection on our practice, we derive a set of insights as to the qualities of tasty fluidics and its utility in the exploration of food as a computational artifact. Moreover, through the development of an extended analogy of food-computational integration, we provide a first-hand account of an interrogation of what it means to design food as computational artifact and offer new ways to empower food creators to innovate future human-food interactions in contemporary gastronomic narratives.

Keywords and Phrases: Food; fluidics; food-computation integration; programmable food; human-food interaction.

1 INTRODUCTION

An increasingly common theme in HCI is the effort to “weave together” the digital and physical worlds (Ishii et al., 2015; Lakatos & Ishii, 2012; Wiberg & Robles, 2010) as interaction design has become a “material concern”, highlighting a system’s material properties (Vallgårda & Redström, 2007; Vallgårda & Sokoler, 2009; Wiberg, 2018). However, this “material concern” can often be overlooked when it comes to the design of human-food interactions (Altarriba Bertran et al., 2019b; Comber et al., 2014; Comber et al., 2012; Deng et al., 2021b; Khot et al., 2019), where food’s material affordances (Fisher, 2004) appear to have been underutilized because of a technology-driven research agenda. Consequently, many systems appear to fail to fully realize the potential to “celebrate the pleasurable and enjoyable experiences that people have with food” (Grimes & Harper, 2008) derived from the food material’s properties emphasizing its aesthetic, affective, sensual and sociocultural qualities.

Recent research on food-computation integration (Deng et al., 2022b) proposed that the emergence of “material integration” could be understood as a new approach to developing future designs for human-food interactions. Deng et al. (2022b) conceptualized the notion of “food as computational artifact” to understand how food as a material can be a medium through which computation is realized. In this article, we extend this prior work by taking inspiration from the concept of “unconventional computing” and embedded (or material computation) (MacLennan, 2012, 2021; Stepney et al., 2005) which are grounded in the intention to conceive “other ways to compute” (Adamatzky, 2021). We note that traditional computational devices are generally influenced by concepts of central control and perfection. However, the notion of “computation” has constantly evolved according to current research of “unconventional computation”, which considers computability and programmability in a more general sense that step away from the concept of universality, especially, when it comes to the material realizations of computation. In line with this view, we propose an alternative way to compute by introducing “tasty fluidics”, a novel design scheme employing a fluidics system made of food, to realize the computation. We present our exploration of the qualities of tasty fluidics and the mechanisms that allow food items to perform basic forms of computation: in this research, the logic operations, AND, OR, and XOR can be hydrodynamically induced by flavorful fluids. Consequently, the food itself can computationally regulate its flavor in response to diners’ inputs. Such food-computation integration enables food creators to essentially “program” the food, and the diners can initiate the “execution” of the program based on given parameters (i.e., the inputs diners operate through the choice of flavors and sequences). The computation results in different flavor combinations that the diners then consume.

Our work constitutes an initial exploration of how to design food as computational artifact through engaging with tasty fluidics. As a result, we derive a set of insights from reflecting on our “Research through Design (RtD)” (Zimmerman & Forlizzi, 2014) practice from ideation to fabrication. Moreover, through the development of an extended analogy of food-computational integration, we provide a first-hand account of an interrogation of what it means to design food as computational artifact and offer new ways to empower food creators to innovate future human-food interactions in contemporary gastronomic narratives.

2 RELATED WORKS

2.1 State of Art in Human-Food Interaction

There has been a notable increase of works across Human-Food Interaction (HFI) highlighting the exciting possibilities enabled by technology to impact our food practices and experiences (Altarriba Bertran et al., 2019a; Comber et al., 2014; Deng et al., 2021b; Khot et al., 2019; Mueller et al., 2020; Velasco et al., 2021). We have seen that researchers have begun experimenting with emerging technologies to pave new ways of interacting with food, including digital gastronomy (Zoran, 2019), food printing (Khot et al., 2017; Sun et al., 2015), virtual reality (Arnold et al., 2018), capacitive sensing (Heller, 2021; Wang et al., 2018; Wang et al., 2020), robotics (Mehta et al., 2018), electrical muscle stimulation (Niijima & Ogawa, 2016), acoustic levitation (Vi et al., 2017), and shape-changing interfaces (Nishihara & Kakehi, 2021; Wang et al., 2017). However, we note that the existing human-food interaction design appears to be predominantly a technology-driven endeavor highlighting the functionality and novelty of computing technology. Such technology-centric approach might outweigh the exploration of inherent affordances of food, such as the food's material properties emphasizing its aesthetic, affective, sensual, and sociocultural qualities.

We note that existing human-food interaction approaches appear to be predominantly technology-driven endeavors that highlight the functionality and novelty of computing technology. This technology focus risks hindering the exploration of the inherent affordances of food, i.e., the user actions afforded by foods material properties emphasizing its aesthetic, affective, sensual, and sociocultural qualities. Prior works inspired us to explore the possibilities for encoding computational capabilities (including actuation and sensing) into food materials. For example, researchers experimented with encoding active structures into food materials so that the food physically transforms in response to external stimuli (Kan et al., 2014; Wang et al., 2017). However, these works, so far, realized only "fixed" process, i.e., a one-off change of state according to predefined behaviors, and hence they are not modifiable once produced. Interestingly, prior research on "material integration" (Deng et al., 2021a) envisaged a future of "cyber food" experiences by conceptualizing the notion of "food as computational artifact". Therefore, our research attempts to expand the scope of "material integration" by exploiting the material's physical process for direct realization of a computational process, that is, using computational concepts and techniques to achieve desired physical behaviors and effects to facilitate dynamic "inter-actions" (Wiberg, 2018) between diners and food.

2.2 Fluid as Computational Material

Despite computers being historically in mostly solid form, including initially using gears (*Antikythera mechanism*, 2021), then vacuum tubes (*Vacuum tube computer*, 2021), and now circuit boards, a computer does not necessarily need to be solid. Fluids can also perform computation (Adamatzky, 2019). For example, researchers have exploited fluids to embed computation directly into material substrates (Adamatzky, 2016; Blikstein; El-Atab et al., 2020; Garrad et al., 2019; Zhang et al., 2017), and an early analog computer used hydraulic components to simulate dynamic systems of the economy (Bissell, 2007). Also, Mor et al. (2020) developed multiple analog fluidic sensors that enabled primitive venous structures to function as a responsive display of information. Alongside analog fluidic computers, fluidic devices have been developed to accomplish digital computation via logic gates – the most basic form of a computer – ranging from standard binary logic operations (e.g., AND, OR and XOR) (Reid, 1969) to more complex functions including the buffer, latch, flip-flop, and even the microprocessor (Belsterling, 1971; Dummer & Robertson, 2013; Foster & Parker, 1970). For example, research has integrated computational logic into a pressure-driven 3D microfluidic chip (2020). Furthermore, it is possible to extend this fluidic logic to incorporate complex computation and allow for the control of soft autonomous robots (Garrad et al., 2019; Wehner et al., 2016).

Overall, prior works demonstrate that fluid's unique physical properties and mechanism make them versatile materials for use in performing computations. More importantly, we note that fluids, such as soup, broth, coulis, liquor, and syrup, are all essential elements that enrich our flavor experiences and some foods (mostly desserts) contain a fluid center (e.g., liquor and syrup). Hence, we started to design and experiment with fluidic systems, and we attempted to realize basic computational operations utilizing food material. This has raised an overarching question of: *What does it mean for food to be computational artifacts?*

3 METHOD: RESEARCH THROUGH DESIGN OF TASTY FLUIDICS

We engaged in a Research through Design (RtD) process (Zimmerman & Forlizzi, 2014; Zimmerman et al., 2007) whereby the design of a novel artifact, as a reflective practice, is a source of new knowledge that is "topical, procedural, pragmatic and conceptual" (Gaver, 2012). In this way, we used our design practice as an exploratory mode of inquiry to uncover the nature of designing food as computational artifact. We see our design not as a final product but rather as a "material speculation" (Wakkary et al., 2015) within the RtD tradition. We intend to create a novel artifact as a research vehicle to provoke possible world accounts which extend the inquiry beyond the artifact itself through experiencing it in real-world scenarios. In other words, we see the artifact as a proposition "being at the boundary of the actual and the possible", to speculate and inspire possible HFI futures (Dunne & Raby, 2013; Wakkary et al., 2015).

4 TASTY FLUIDICS

We conceived the idea of "tasty fluidics" and attempted to exploit integrated fluidic mechanisms to create food capable of computationally configuring its properties, specifically, its flavor and visual presentation (i.e., color). We began engaging with fluidics to explore how we can computationally control the fluids running through a food item. To understand the fluid's properties and dynamics, we designed a fluidic system that performs basic logic functions based on prior research of fluidic devices (Belsterling, 1971; Reid, 1969). Figure 1 summarizes the configurations of three basic fluidic logic devices (AND, OR, and XOR) (Reid, 1969).

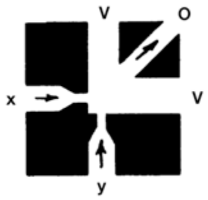
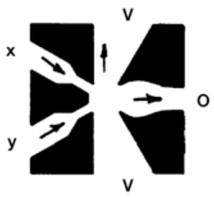
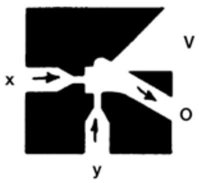
	AND	**OR**	**XOR**
Logic function	Output (O) if both inputs (x, y) are on	Output (O) if one or both inputs (x, y) are on	Output (O) if either inputs (x, y) are on but not both
Typical configuration of fluidic logic gate (Reid, 1969)			

Figure 1: Configurations of three basic fluidic logic devices (AND, OR, and XOR) (Reid, 1969).

Through our initial exploration of the fluidics systems, we gained the following insights to optimize our initial design to realize logic functions using fluidic mechanisms.

4.1 Exploit basic fluid dynamic phenomena

According to prior research (Belsterling, 1971; Dummer & Robertson, 2013; Reid, 1969), basic fluid dynamic phenomena underlie the design of any fluidic device. For example, some logic functions can be achieved via particular fluidic configurations using a fluidic "jet-on-jet interaction", called the "beam deflection" (Reid, 1969). Such a mechanism allows fluid flow to be deflected through the interaction with another flow.

Figure 2: Prototyping the fluidic system. a) Design sketches of fluidic configurations; b-c) Fabrication of the fluidic devices; d-e) Testing the fluidic system.

However, according to prior research, the typical configurations of fluidic logic gates were conceived to "illustrate the functions" rather than "represent actual designs for achieving flow mechanisms" in the real world (Reid, 1969). We began sketching, crafting, and evaluating various fluidic devices with simplified fluidic configurations to achieve three commonly used logic functions: AND, OR, and XOR, which two-jet beam deflections can execute. For fast prototyping, we initially designed and fabricated a number of fluidic devices made of acrylics, and used an Arduino-controlled pump and applying pressure to introduce the water into the fluidic devices. The water was dyed using two food colors (red and blue) (Figure 2).

4.2 Consider switching fluidic ports to realize multiple logic functions

Our findings suggest that we could achieve multiple logic functions by simply changing the output and vent ports. For example, an XOR gate can be made by simply switching the vent(s) and output ports by utilizing the AND configuration. This means that we can make a XOR gate from an AND logic configuration, but the out ports need to be reconfigured: specifically, the vent ports become two output ports (Ox and Oy), and the original output port becomes a vent. Figure 3 shows the configurations of three common fluidic logic gates we designed and their corresponding fluid flows.

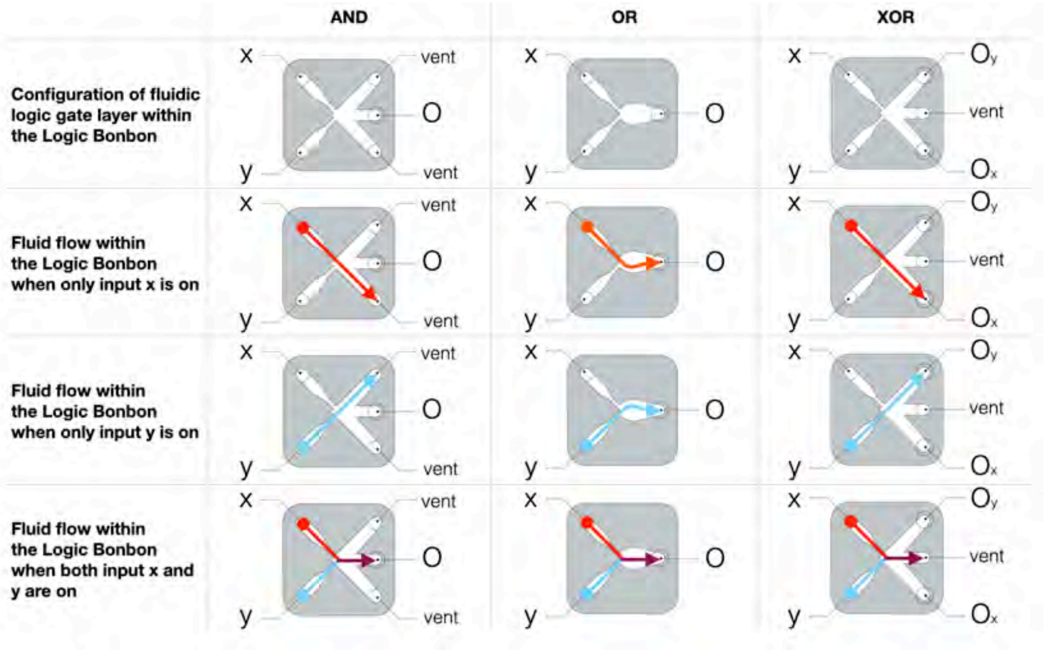


Figure 3: Our design of the configurations of three common fluidic logic gates along with their fluid flows

4.3 Adjust fluid flow manually

Prior work demonstrated that the amount of pressure applied to the inputs of fluidic computing could significantly influence the logic gates' proper functioning (Foster & Parker, 1970). We used two methods to input the fluids into the fluidic devices: first, using miniature water pumps (DC6V, flow range: 0-100 ml/min) controlled by an Arduino microcontroller, and second, manually applying pressure with our hands using pipettes. We found, to our surprise, that manually controlled fluid inputs worked better than using the electric pumps and improved the chance that logic functions would be properly performed. This difference might have occurred because manual control enabled a sensorimotor coupling (Dijk et al., 2014) that facilitated a more direct interaction between the diner's actions (i.e., pressing) and their perception (i.e., visual feedback of the flow), which allowed for a more finely-tuned fluid flow compared to a fixed pressure automatic system. Figure 4 shows how a AND gate works by manually operating two pipettes as a replacement of the pumps.

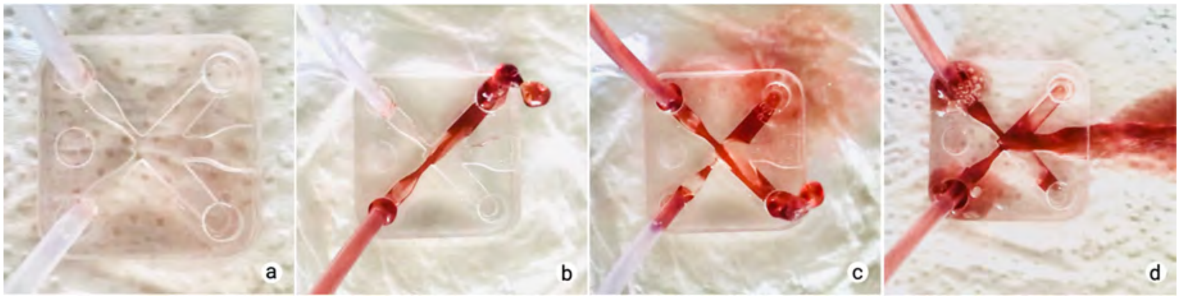


Figure 4: An example of an AND gate using pipettes. a) The logic function returned FALSE (that is, no fluid exiting from the output port in the middle on the right) if both inputs were off. b-c) The logic function returned FALSE if the fluid exited the vent ports on either the upper or lower right when only one input was on. d) The logic function returned TRUE if the fluid went out from the output port (in the middle on the right) when both inputs were on.

We note that in the realm of computing, it is often believed that manual control might cause uncertainty that compromises the precision and efficiency of computation. However, prior HCI research suggested that ambiguity (Gaver et al., 2003) as a result of manual control can provide "rich resources" to "establish deeper and more personal relations with meanings" offered by those systems, which can, in turn, "encourage close personal engagement with systems" (Gaver et al., 2003). Furthermore, we note that manually controlling pressure with the hands is common in many culinary scenarios, such as when piping frosting into certain shapes to decorate a cake, or when squeezing the desired amount of sauce onto food.

5 DESIGNING THE LOGIC BONBON

Building on our initial design exploration findings, our next question was: *How can we design a food exploiting fluidics?* We aimed to empower diners to use edible fluidics to change their food's taste and visual appearance according to their preferences in the moment between being served and beginning to eat their dish. We hoped that such real-time modification opportunities could potentially provide additional benefits, such as enriching sensory perceptions and aesthetic appreciations, by building on the fact that taste and vision are key sensory modalities that contribute to pleasant food experiences (Schifferstein et al.; Spence, 2017). Furthermore, to avoid the common pitfall of designing technology-driven food interactions that neglects the aesthetic, sensory and social qualities of food (Deng et al., 2022a), we prioritized the food's palatability and the experiential pleasure gained from it, rather than using only "adequate" edible material (that is, food materials that work great with fluidics, but might not taste nice) to house the computation.

We conceived the idea of the "Logic Bonbon" after noting that some desserts contain a multi-flavored center and that traditional bonbons contain a liquor or coulis center that can enrich the flavor experience. We sought to create a Logic Bonbon dessert capable of computationally configuring its properties (flavor and visual presentation) by using integrated fluidic mechanisms to execute logic operations in response to external diner inputs (Figure 5). The detailed design process of the Logic Bonbon can be found in our previous work (Deng et al., 2022b). Here in this article, we attempted to further elicit the insights into food as computational artifact via tasty fluidics through reflecting on the construction and fabrication.

Figure 5: Eating a Logic Bonbon with an AND gate. a) No flavor outcome inside the logic Bonbon when only one flavor input is on; b) The flavors are mixed inside the Logic Bonbon when both inputs are on.

5.1 Construction

Our initial exploration suggested that a basic fluidic system ought to consist of a set of fluid reservoirs as inputs, a logic gate, and a flavor chamber inside the dessert as output. To maximize the system's flexibility and variety in terms of the material being used, we attempted to modularize the functional parts (i.e., the fluid reservoirs, logic gate and flavor chamber), into discrete, scalable, and reusable modules (Figure 6). Another special feature in our design was the utilization of the transformative nature of fluidics as a functioning display.

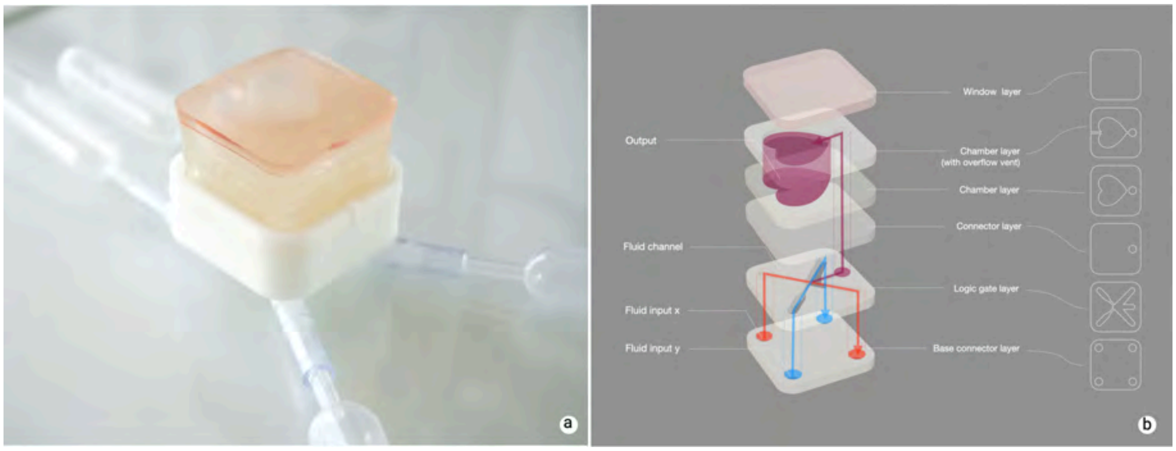


Figure 6: a) A Logic Bonbon system; b) Schematic structure of a Logic Bonbon

5.1.1 Modularize the system for flexibility

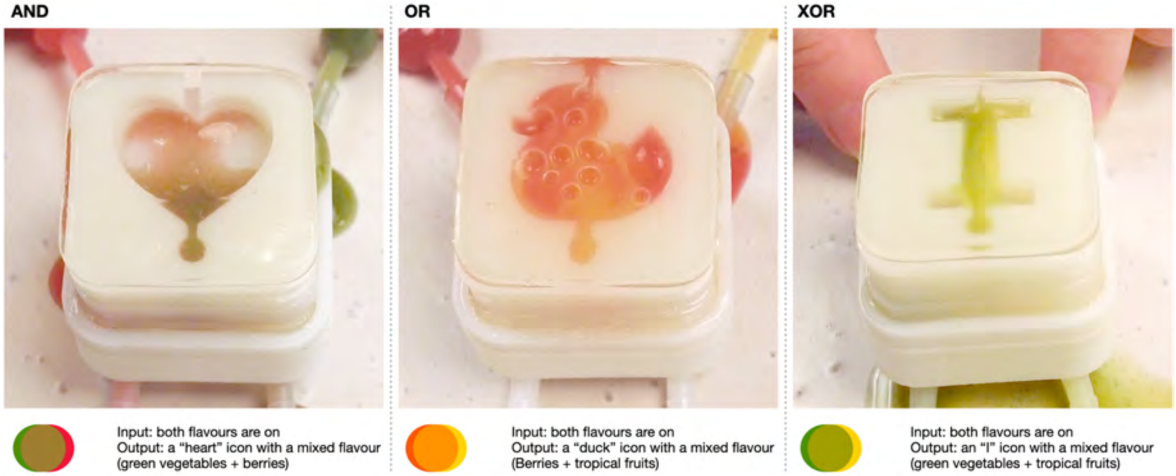
A computer might be one of the best examples of modular design. Typical computer modules include power supply units, processors, mainboards, graphics cards, hard drives, and optical drives. All these components are easily interchangeable where they support the same standard interface. Modularization is also increasingly employed in the food and gastronomy industries to increase production and facilitate customer personalization.

Based on our experience and reflection of using a modular approach, we suggest that designers consider modularization, allowing diners to choose which flavors they want by simply exchanging the fluid reservoirs. In addition, if the flavor outcome from a logic operation is not as the diner expected, they can replace the bonbon (i.e., the output module), avoiding material waste. Furthermore, diners can adjust the positions of each independent module to best suit their dining situation. For example, diners can adjust the angle of the two reservoirs to facilitate a two-diner eating mode.

5.1.2 Utilize display as complementary feedback

Computer interfaces traditionally depend on visual feedback (usually screens) to display information in texts or pictorial form to the user. One essential feature of the Logic Bonbon is the responsive visual display due to the dynamic nature of the fluids integrated into the dessert. We note two things that make a food's visual qualities essential to culinary practices: first, they can influence our sensory perceptions; and second, they can indicate whether or not a food is ready to eat. For example, as popcorn explodes, its crunchy-looking, and the brownish-caramel color produced by the Maillard reaction indicate that the food is becoming flavorful.

Our design practice revealed that the Logic Bonbon "display" (arising from the logic functions) provides complementary feedback about flavor, which informs diners when to eat. In this respect, we used three different pictograms to differentiate the three logic functions (Figure 7).


AND

Input: both flavours are on
Output: a "heart" icon with a mixed flavour
(green vegetables + berries)

OR

Input: both flavours are on
Output: a "duck" icon with a mixed flavour
(Berries + tropical fruits)

XOR

Input: both flavours are on
Output: an "I" icon with a mixed flavour
(green vegetables + tropical fruits)

Figure 7: Three different pictograms to differentiate the three logic functions.

5.2 Fabrication

We investigated two fabrication techniques: food 3D-printing, and molding. Our results suggested that 3D food printing has the advantage of being able to produce the entire structure at once, without additional tooling. However, food 3D-printing usually resulted in a lower resolution of the food outcome when compared with the 3D rendering in the software, and this lower resolution hindered the correct execution of the fluidic logic functions. To overcome this problem, we created a set of molds to fabricate the different layers of the Logic Bonbon. This process allowed for a higher resolution, and the fluidic logic functions performed more effectively. We also elicited two insights from our fabrication process, as articulated below.

5.2.1 Create a multi-layered structure as a design solution for fluidics

We suggest that designers consider a layered structure for tasty fluidics. Utilizing a multi-layered structure is a common production technique in computer and electronics manufacturing. For example, most contemporary computational devices are designed with multiple layers of circuit boards that are laminated together. Additionally, most microfluidic chip designs use layering techniques to regulate flow. Similarly, a layered structure is common in food production because it helps to enrich flavor and sensations inside the mouth (e.g., burgers and sandwiches). We took these models as inspiration and fabricated the Logic Bonbon with a multi-layered structure.

We found that the multi-layered structure of the Logic Bonbon allowed for a more effective performance of the fluidic logic functions and enabled us to configure each layer separately. As a result, designers can change the logic function (i.e., replace the AND gate with an XOR gate) or the visual presentation (i.e., replacing the chamber layers) output of the Logic Bonbon by simply replacing certain layers (e.g., the logic layer, or the chamber layer) (Figure 8).

Figure 8: a) Molding the layers; b) Making a Logic Bonbon by stacking the layers together; c) A ready-made Logic Bonbon without fillings

5.2.2 Consider the trade-offs between computational validity and gastronomic palatability

Our findings also suggest that computational validity and gastronomic palatability are often in a trade-off relationship when designing food as computational artifact. We base this insight on the fact that food is often fragile (e.g., crisps can be crushed), unstable (e.g., sugar can become damp) and ephemeral (e.g., many foods have a limited shelf-life). However, a fully functional computing machine often requires material durability and rigidity, while such qualities might be suboptimal from a diner's point of view. Considering these qualities (and the associated trade-off), we found that working with food-based materials brings design and fabrication challenges.

In our design of the Logic Bonbon, the ingredients we found to be suitable for the fabrication process restricted the food's palatability and aesthetics. The qualities of the material (i.e., rigidity, elasticity, hydroscopicity) essentially determined whether the computation could be properly performed. We explored three different recipes, each containing a different gelling agent that made the food material shapeable and less hydrophilic to assist with the performance of fluid-induced logic functions. However, we found that slightly different ratios of ingredients produced varied outcomes, even when following the same recipe.

The shelf-life of food is another factor restricting computational validity in our design. In comparison to working with traditional computers, we found that working with food requires different time management because food commonly has a shorter shelf-life. To maximize the Logic Bonbons' work life, they must be stored in a refrigerator. We note that, even when refrigerated, the Logic Bonbons gathered mold after three weeks.

6 DISCUSSION

Based on the observation that people often use food analogies in non-expert presentations of computational concepts, we utilized food-computation analogies as an initial conceptual resource. For example, our daily food processing can be regarded as a computational process. The culinary process leads to changes in the state of food (e.g., colors, shapes, flavors) that can occur by controlling a data set (e.g., altered ingredients, condiments) based on an algorithm (e.g., a recipe) and external inputs (e.g., heating, blending). However, we acknowledge that analogies like these are used to rhetorically establish a preliminary relationship between two domains. Through reflection on our design practice, we attempt to extend the analogy of food and computation to unpack the meaning of food as computational artifact. By focusing on "programming food" and "shifting control", we discuss how computational qualities of food could be leveraged in the development of novel human-food interactions and shape the future of food innovation.

6.1 Programming food: towards a new lexicon

Our exploration of tasty fluidics demonstrated the possibility of endowing food with computational capabilities. The Logic Bonbon executes the fluidic configuration of logic functions in response to the inputs of the diners, which means that the food can be possibly "programmed". There exists a small number of previous experiments with the programmability of food materials, including computationally generated taste structures in a mousse cake (Zoran & Cohen, 2018), and the encoding of active structures into food materials that enable food to physically transform in response to external stimuli (Kan et al., 2014; Wang et al., 2017). Our work extends the notion of "programming food" because tasty fluidics serves simultaneously as a physically programmable composite defining the logic functions, and as a medium facilitating reconfiguration. In other words, the food's physical state and the logical state are inseparable in our design. Diners can initiate the "execution" of the predefined logic functions, and, at the same time, "reconfigure" the food through their selection of flavor inputs.

The ability to program food affords a new lexicon that could bridge the language gap between the food and computational worlds and help further elaborate the meaning of food as computational artifact. For example, we have used the term “program” to denote the culinary practices (e.g., cooking) by which chefs encode the logical function. Also, to characterize the changes in state caused by executing the program, we have used “physical state” and “logical state” to distinguish between changes in the form/structure and function of the food, respectively. Lastly, “reconfiguration” describes how diners initiate the “execution” of the program; they reconfigure the food by controlling different “inputs” (i.e., the sequence, and numbers of flavors being introduced into the food), which results in different “outputs” (i.e., flavor outcomes within the food).

This proposed vocabulary can be a useful aid for communicating an understanding of the features and characteristics of food and its computational qualities. This communication is particularly important in an endeavor such as food innovation, which draws on multiple disciplinary and practitioner assumptions and traditions. For example, chefs and technologists can use a shared language to describe design concepts and rationales; likewise, consumers and critics can also use the language to express their feelings and experiences with new gastronomic poetics of “tasting” a computer. Moreover, this vocabulary can also be the basis for a new discourse through which creators can reimagine food and computation, and thereby circumscribes a new design space. Finally, through specifying the lexicon, we hope to provide designers with analytical and generative conceptual tools that potentially support the processes that are core to design (e.g., abstraction, abduction, experimentation).

6.2 Shifting control: relationships in transformation among users

In the context of this research, the concept of “control” refers to the people who program and interact with the food system, and their influence over it. In tasty fluidics, we noted that the relationship between the diner and the creator was transformed, specifically in terms of the relative degree to which they exercise control over the final dish. This relationship is no longer one in which the creator admits the diner unfettered control over the application of elements of a dish (e.g., condiments) to eat in all sorts of combinations (including flavors that do not go well together). Rather, the creator’s “programming” of the food is an act of bounded control over the final dish, perhaps preventing some flavor combinations. However, the creator is still not in full control but can be more deliberate (might be more explicitly creative in their intent) in offering the diners parameters for experimentation. In our design, parameters comprise the inputs that diners operate through their choice of flavors, sequences, and the amount of pressure they apply when introducing the fluids into the Logic Bonbon.

Our research suggests that a more nuanced and dynamic interaction between creator and consumer can be facilitated through shifting the control over the dish. Such shifts in control provide opportunities for creators to engage in discourse with the diner. On one hand, chefs, through their programming, could encode their visions into each step, action, and thread within the food journey, thereby offering a space of aesthetic opportunities for diners to explore. On the other hand, appreciating a meal becomes a way for diners to respond to the chef through their interactions with the dish. Furthermore, these shifts in control carry the potential to elevate the act of eating to the status of an artwork that is composed by the chef’s and performed by the diner.

This change in locus of control also has implications for what it means to “serve” and “be served”. Diners have always been “served” in formal settings, such as in a restaurant or at a banquet, diners only need to wait for their food to be provided or simply exchange and pass food to each other. In contrast, we have attempted to open a new space where a chef can enlist diners into the performance in supporting other diners to complete the dish and eating experience through jointly controlling over the dish (Figure 9).

Figure 9: Diners are co-eating a Logic Bonbon through jointly reconfiguring the program

7 OUTLOOK

In this section, we depict several potential application scenarios as a way of envisioning how our work might contribute to different fields and sectors.

7.1 Interactive food for engaging food experiences

Our design of tasty fluidics presents the food and hospitality industry with new business opportunities to provide novel experiences via interactive food. Specifically, we hope to enrich food manufacturers’ product lines (e.g., interactive biscuits and chocolates that change flavours and appearance) and inspire restaurants to deliver novel dishes (e.g., dishes that change their tastes and aromas in response to the diner’s actions and preferences).

7.2 Tasty fluidics as aid in promoting healthy food choices

Tasty fluidics has the potential to contribute to the promotion of healthy food choices, with the food’s dynamic visual feedback improving diners’ awareness of their diets. For example, a dish or food item contains an integrated fluid display which indicates calorie intake, and the display would vary according to the diner’s inputs, so that they can adjust the intake of calories according to their personal need.

7.3 Edible fluidics systems for advancing ingestible technology

We can also envisage our approach to advance ingestible technology (Li et al., 2020; Miyashita et al., 2016) with novel fluidic sensors and devices, to be used by the healthcare industry, especially in hospitals and nursing homes. For example, our approach could be used for developing drug delivery devices (e.g., digestible soft robots) that can be self-actuated according to a specific gastrointestinal environment (e.g., PH value, microbiota, and temperature) and release different drugs at desired points along the human gastrointestinal tract.

7.4 Computational food as edible interfaces to support multimodal learning

Our work could also bring benefits to the education sector, especially in computer science pedagogy in schools or other education institutes. Specifically, teachers could employ tasty fluidic systems as engaging teaching aids to deliver multimodal learning (Sankey et al., 2010) that offers students a "behind-the-scenes" look at basic computer science concepts through delivering a playful, flavourful, and more effective learning experience, and, thereby, improve students' learning experiences and learning outcomes.

7.5 Edible system designs for sustainability

We also hope that tasty fluidics can contribute to the development of contemporary works of non-electric robotics (Decker et al., 2022) by encouraging sustainable designs that use fully biodegradable and biocompatible fluidic systems.

8 LIMITATIONS AND FUTURE WORK

8.1 Fluidic dynamics in food design

We note that tasty fluidic systems sometimes result in unpredictable outcomes even when using the same logic function. This unpredictability is due to the inherently turbulent nature of fluidic mechanisms, in which flows are characterized by recirculation, eddies, and apparent randomness. This unpredictability can also arise from inaccuracies in the fabrication process, the properties of the selected fluids (e.g., their viscosity, and temperature), and the diner's inputs (e.g., the pressure they apply when using the mechanism). Future exploration of fluidic mechanisms in combination with fluids' properties will be useful for an additional understanding of food as computational artifact.

8.2 Fabrication technique

So that we could achieve precise fluidic configurations that properly perform the logic operations, we made the Logic Bonbon using a more traditional fabrication technique (molding). However, this technique required extensive preparation and labor, such as tooling (i.e., creating the molds), and limited production quantity. We envisage future possibilities to use advanced 3D food printing technology to mass produce delicate food artifacts, of high-end precision and quality, that can complete more complex and accurate computational operations.

8.3 Extension of computation and food materiality

In this work, we explored basic fluidic logic gates to understand food as a computational artifact. We acknowledge that this work provides only one example for realizing computation and we encourage future explorations of other forms of food-computational integrations that achieve other forms of computation. This work might also require the exploration around other food-based materials, responding to the fact that working with food brings design and fabrication challenges. In the case of the Logic Bonbon, the ingredients that we found to be suitable for the fabrication process restricted the food's palatability and aesthetics. The material's stiffness, elasticity, and durability determined whether the computation could be properly implemented, which limited the diner's pleasure when eating the Logic Bonbon. Future exploration of food properties such as physical-chemical properties (e.g., electrical, and thermal conductivity) and kinetic properties (e.g., biological changes and growth) might extend our understanding of food as computational artifact and better address the trade-offs between fabrication, palatability, and aesthetic outcomes.

9 CONCLUSION

This article showcases our exploration of an edible computational material resulting in a novel design scheme, called "tasty fluidics". Through examining the qualities of tasty fluidics and their utility, we provide a set of pragmatic insights into design food as computational artifact. As such, our research is in the service of expanding culinary practitioners' and designers' material repertoire of creating new recipes and novel food experiences for consumers. Furthermore, our work opens a new design space of food-computation integration in the emerging field of human-food interaction. As this field has undergone rapid growth over the past decade but has been predominantly a technology-driven endeavor, it has largely been guided by technological capabilities rather than food's inherent affordances highlighting the food's material properties emphasizing its aesthetic, affective, sensual, and sociocultural qualities. In contrast, our research seeks to explore designs in which food, as a material, is the medium by which computation is realized. Through using our design practice as an exploratory mode of inquiry, our research attempts to uncover the nature of designing food as computational artifact. Specifically, this research provides a first-hand account of a new lexicon for people to communicate an understanding of food and its computational qualities in an endeavor of food innovation, which draws on multiple disciplinary and practitioner assumptions and traditions. Furthermore, by discussing a transformative relationship between food creator and consumer, we aim to reveal how computational qualities of food could leverage the power of developing novel human-food interactions to shape the future of food innovation in contemporary gastronomic narratives.

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